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EFFECTS OF CHEMICALS ON EARTHWORMS: A REVIEW OF THE LITERATURE

By

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CONTENTS

	Page
Foreword	1
Introduction	3
Botanicals	3
Mowrah meal	3
Rotenone	4
Inorganic chemicals	4
Ammonium sulphate	4
Calcium arsenate	5
Lead arsenate	5
Organic chemicals	5
Aldrin	5
Aramite	6
Lindane (gamma BHC)	7
Captan	8
Chlordane	8
DDT	9
Dieldrin	11
Endrin	12
Heptachlor	12
Monuron	12
Tetram	13
Toxaphene	13
Guthion	13
Malathion	14
Parathion	14
DD	15
Miscellaneous chemicals	15
Discussion and conclusions	15
Bibliography	16

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FOREWORD

Production of synthetic organic pesticides in the United States exceeded 700 million pounds in 1962. Persistent types made up significant proportions. By excluding exports and accounting for previous year's stocks, Shepard et al. (1963) estimated the year's domestic "disappearance" of DDT at more than 67 million pounds and of the aldrin-toxaphene group at more than 82 million pounds.

Several studies have shown that pesticides of persistent types can accumulate in the bodies of animals to such an extent that the contaminated animals cause fatal poisoning of other animals that feed upon them. This concentration of pesticides through the food chain has been shown especially well in lakes. There a chemical applied at the rate of a fraction of 1 part per million may be concentrated in small organisms and be further concentrated in the fish that prey on these organisms. The fish may come to contain hundreds or even thousands of parts per million of the chemical. Birds that eat such fish may be killed in considerable numbers.

Concentration of pesticides by animals in terrestrial situations has not been demonstrated so thoroughly, but Barker (1958) found that living earthworms from areas treated for control of Dutch elm disease contained DDT in amounts that could be fatal to robins that fed on the worms. Other workers have attributed mass mortality of robins to this cause. Work of the Fish and Wildlife Service (unpublished) has shown that earthworms contaminated with heptachlor at levels often found in treated areas are fatal to woodcock that feed upon them for a few weeks. And we know that animals that receive less than a fatal amount of pesticide may suffer impaired reproduction. This is one of the factors that has been suggested as responsible for poor reproduction by bald eagles in the eastern United States.

The Fish and Wildlife Service has been especially interested in earthworms because of their importance as food for woodcock, robins, and other animals, and because reports from workers trying to control earthworms indicated that worms were surprisingly resistant to chemicals and thus were very likely to become dangerous carriers. As one approach to this problem, a survey of literature was made to learn what was known of the susceptibility or resistance of earthworms to pesticides Since the results of the survey are of interest to workers in several fields, it was thought best to present them in significant detail in the form of a review paper.

Many of the papers were reviewed a second time to make sure that the name of the species was given if the author provided it and to standardize the expression of rates of application so far as possible. Authors varied widely in their practices, some testing worms in standardized solutions, others judging results from signs of earthworm work in the field. Some did not tell what the formulation or the rate of application was. Others did not name the species [at least 17 native species and 13 introduced species of earthworms occur in the area east of the Mississippi and north of Virginia (Eaton 1942)].

The worm most usually and most easily grown and hence most often used in experiments is the red worm or manure worm, Eisenia foetida, which appears to be extremely resistant to chemicals. The red worm is a creature of moist, highly organic sites where chemical concentrations are high. Most common worms of field and garden could not survive such conditions. Hence, use of the red worm in experiments is quite unwise if the results are to be applied to other earthworms.

The general conclusion to which we wish to direct attention is that earthworms are indeed resistant to most chemicals, even at levels considerably higher than those used to protect crops from insects. It is extremely probable that, throughout the portions of the world that are treated with residual pesticides, earthworms are carrying burdens of toxicants. Some must be carrying several toxicants.

If this is true, why have wildlife effects not been reported more commonly? Perhaps because they have so seldom been sought, perhaps because they occur so long after the application that they are ascribed to other causes. They may be spread over such an extended period that they are not observed. There are, however, several factors that serve to reduce the danger. Some chemical applications are not great enough to produce severely contaminated worms. Some soils hold the chemicals poorly. Earthworms are scarce in some soils, abundant in few. They are available in numbers to predators only at certain times. Most predators tend to spread their hunting over large areas; thus they are likely to feed on untreated areas part of the time unless large blocks are treated. And the predators are likely to feed partly on organisms less contaminated than earthworms, for few kinds of animals feed primarily on earthworms.

The problem does not end with earthworms, however. Snails and other mollusks are resistant to pesticides and some contain large residues They are important wildlife foods. Other invertebrates, aside from insects, have hardly been studied in this connection. Insects themselves must carry significant residues whenever contamination of the environment is within their tolerance limits. Clearly the problem is a pervasive one of which little is yet known. It seems safe to say, however, that the severity of the problem is bound to vary directly with the use of residual pesticides.

- William H. Stickel

EFFECTS OF CHEMICALS ON EARTHWORMS: A REVIEW OF THE LITERATURE.

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Most tests of the effects of chemicals upon earthworms have been made with the purpose of learning how to control the earthworms in areas such as golf greens, where the worms are not wanted. Other tests have been made to learn possible effects of fertilizers on earthworms in crop fields, where the worms are wanted for the good they may do in soil aeration and mixing. More recently, some tests also have been made to determine the effects on earthworms of pesticides applied for other purposes.

The principal results of these studies, as learned from a review of the literature, are summarized here. For convenience of organization and reference, the review is arranged according to chemical, rather than according to the purpose of the particular study. Chemicals are grouped as botanicals, inorganic chemicals, and organic chemicals.

The difficulty of making dependable experimental studies of soil fauna and pesticides was discussed by Satchell (1955), who pointed out that the apparent absence of effects sometimes may have been the result of poor experimental design in the face of highly variable population distributions. The problem also was discussed by Kuenen (1957), who noted that mortality of experimental animals was not normally distributed and that therefore there was not complete independence of action between toxicant and mortality. A thorough review of the soil insecticides used from 1914 to 1940 was made by Gough (1945). This, of course, involved none of the modern chemicals, but nevertheless is of considerable value. The present review is intended to be descriptive rather than analytical, but so far as possible the facts that will affect a judgment are included. The species of earthworms tested are listed if this information was included in the original paper. Treatment rates are expressed as actual amount of chemical per unit area, not as the amount of formulated mixture.

BOTANICALS

Mowrah Meal

Mowrah meal, a product of the Indian tree bean of the genus Illipe, has been used as an earthworm expellent. Bingley (1949) reported its effectiveness, but noted that the cost was high. He gave no further details.

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Jefferson (1955) reported that the "mowrin" of mowrah meal was the active earthworm expellent. He used it in preference to other expellents in his earthworm population studies in England. However, he did not report the specific methods of application. He recommended that any expellent be used only during the spring or fall, when soil moisture and soil temperatures were conducive to earthworm activity in the upper soil levels.

Rotenone

Rotenone (derris root) also has been used as an expellent as well as a toxicant. Bingley (1949) reported its value as an expellent, but also commented on its cost.

Harris (1949) reported "optimum" kills of earthworms 24 hours after application of 4% rotenone at the rate of about 6 pounds of chemical per acre. This treatment remained toxic to worms for 6 more days. No further information was given concerning soil type, season, species of worm, or other factors.

INORGANIC CHEMICALS

Ammonium Sulfate

Rodale (1948) reported that 500 lb/A of 4-12-4, ammonium sulfate, or superphosphate reduced populations, activity (as shown by casts), and reproduction of worms. Worms were kept in 6-inch pots where activity and populations were checked in detail after 2 months. At rates of 1,000 and 1,500 lb/A, the chemicals reduced populations further, sometimes killing all worms present.

Jefferson (1955) used experimental plots to determine the effects of various fertilizers upon earthworm population numbers, species, and reproduction. The results often were difficult to measure quantitatively because of climatic changes and the apparently normal population fluctuations. However, the smallest number of species (two) was found on plots treated with ammonium sulfate. Plots treated with dried blood (considered excellent fertilizer) contained up to 10 species. The higher acidity that followed the use of ammonium sulfate was tolerated only by Lumbricus rubellus and Allolobophora caliginosa. Jefferson concluded that "a comparison of the population estimates in 1947 and 1953-54 suggested that a real population decline had taken place in some habitats, e.g., complete fertilizer plots (ammonium sulfate)...."

Calcium Arsenate

Escritt (1955) found that 300 - 450 lb/A (1 - 1.5 oz/sq yd) gave good earthworm control but sometimes damaged the turf. He found no correlation of variation in turf damage with soil texture, pH, phosphates, potash, turf type, season, or weather. He reported good earthworm control for as much as 6 years.

Lead Arsenate

Escritt (1955) mentioned, without further detail, that lead arsenate applied at 450 - 600 lb/A (1.5 - 2 oz/sq yd) gave effective earthworm control for as much as 5 years, or more.

Polivka (1951) obtained different results in his studies made on sandy soil in Ohio. Lead arsenate (without diluent) was broadcast by hand on sample plots at rates from 218 - 653 lb/A (5 - 15 lb/1,000 sq ft). Treatments were made in September. All plots were examined for earthworms the following May (8 months after treatment) and again a year later (20 months after treatment). At neither time were earthworm population changes significantly different from those in control plots.

In a second experiment, Polivka (1951) applied lead arsenate to sandy soil at a rate of 500 lb/A; treatments were made in October. Five years later there was no significant difference between earthworm populations on these treated plots and those on untreated plots.

Polivka (1953) reported variable results in further experiments with earthworms and lead arsenate. On one series of plots treated with 435 lb/A of lead arsenate in April 1948, and examined in October 1951, mean numbers of earthworms per square foot did not differ on treated and untreated plots. On another series of plots, in contrast, the same application rate, 435 lb/A, reduced mean populations to zero, and the populations did not recover even after 5 and 6 years. In a final experiment, lead arsenate was applied to sample plots at rates of 436, 871, and 1307 lb/A (10, 20, 30 lb/1,000 sq ft) in October 1947. Four years later, only the plots that received the highest treatment showed significantly lowered populations. After 5 years, however, all treated plots had mean populations significantly lower than those of untreated plots. Soil differences may have influenced the variability. More samples of earthworms taken at short intervals would have helped in interpretation of results.

ORGANIC CHEMICALS

Aldrin

Aldrin showed no significant effects on earthworms in an experiment reported by Edwards and Dennis (1960).

Aldrin dust (in a 1.25% formulation) was thoroughly mixed into the top 6 inches of soil at the rate of 3.75 lb/A. Field plots were 6 feet square in a randomized block design. All plots were kept fallow with herbicides. Sampling of the plots at intervals of 2 - 3 months revealed no significant effects on earthworms.

Polivka (1953) reported two experiments using aldrin. In the first, the application rates were 1, 5, 10, 20, 40, and 80 lb/A. Treatments were made March 2, 1951, on an Ohio golf course. Earthworm populations were not reduced significantly by May 7, but on June 4 and September 27, populations on all plots treated with 5 lb/A or more were significantly lower than those on untreated plots. There was some doubt of the validity of these results, however, because of natural population changes during the period. In further experimentation, aldrin was used at rates of 1, 3, 6, and 12 lb/A on May 14, 1952. Soil moisture was high (1.42 inches of ran fell in the period of observation) and on June 2, no effects of the treatment on the worm population were ascertained.

Hopkins and Kirk (1957) conducted two laboratory tests of the effects of aldrin on red worms, Eisenia foetida (sp.?). In the first experiment, 2.5% aldrin dust at the rate of 7.5 lb/A was mixed with South Carolina Marlboro sandy loam. No significant mortality had occurred after 2 months. In the second experiment, the worms were exposed to equivalents of 64, 128, and 256 lb/A of aldrin for 4 days. There was no mortality of adult worms at the lowest level, but 93% at the highest level. An LD_{50} at 96 hours was computed to be 170.3 lb/A of aldrin.

In order to control damage to tobacco seedlings caused by earthworms in India, Patel (1960) recommended aldrin emulsion spray at a rate of about 136 lb/A [0.05% emulsion spray; 1 oz aldrex 40, emulsifiable concentrate, in 5 gal (Imperial) water]. One gallon of formulation was used per 16 square feet, more if the soil was dry.

Schread (1952) reported control of Oriental earthworms (Pheretima hupeiensis) on golf greens several weeks after application of aldrin either as a water emulsion or as wettable powder (mixed with fertilizer and soaked in) at the rate of 33 lb/A.

Aramite

Hyche (1956) experimented with several insecticides at different concentrations in an effort to kill mites (Caloglyphus anomalus) in beds of earthworms [Eisenia foetida (sp.?)] but not harm the worms. He used aramite at about 9 - 11 lb/A (2 lb of 15% wettable powder per 100 gal water; 1 gal per 12 - 15 sq ft of bed) and found that both the worms and the mites survived. The lethal rate for the worms was not given.

In a test of the effects of BHC on Lumbricus rubellus and Allolobophora caliginosa, Hoy (1955) found that 21 lb/A produced significant mortality when tests were made in soils of low organic content, but that 20 lb/A produced no significant mortality in soils of medium organic content. The toxicant was mixed with sand, which then was mixed with the soil in experimental pots; tests extended 8 weeks.

In plot tests, BHC applied at 0.25 and 12 lb/A had no significant effect on earthworm populations after 42 months (Polivka, 1953). Polivka also found no significant effects within 5 and 6 years of treatments with BHC at 0.25, 2.5, 5.0, and 10 lb/A.

Satchell (1955) has summarized the results of BHC studies by Goffart (1949), Grigor'eva (1952), Gunthart (1947), Prisyazhnyuk (1950), Richter (1953), and Weber (1953). In general, earthworms were resistant to BHC dressings applied to the soil as dust, but were killed more readily when the chemical was applied in a solution or suspension.

Lindane (gamma BHC)

In conjunction with experiments in the elimination of Pheretima hupeiensis, Schread (1952) tested lindane at 20 lb/A on a golf-green grass nursery in Connecticut. Plots were 60 square feet and the toxicant was applied as a wettable powder and watered in immediately. The areas were soaked with water again after 24 and 48 hours. Treatment was on June 3, and by August 5 worm activity was reduced. There was no further worm activity on the plots even a year later, although untreated plots remained heavily infested. It was not stated whether or not other species of worms were involved.

Hoy (1955) tested the effects of lindane on Lumbricus rubellus and Allolobophora caliginosa. At 2 and 10 lb/A of lindane applied to soil of moderate organic content, there was no significant mortality at 8 weeks. The toxicant was mixed with soil in small jars. At 30 and 40 lb/A, however, average numbers of earthworms surviving were significantly lower than those surviving the 15 and 20 lb/A rate.

Hopkins and Kirk (1957) conducted two tests of the effects of lindane on Eisenia foetida (sp.?). Tests were made in 2-gallon ceramic pots. In the first test, 3% lindane dust was mixed with Marlboro sandy loam (South Carolina) and the worm samples at the rate of 5 lb/6-in A.[1/]

1/ This is a method of expressing amount of chemical per volume of soil that can be envisaged in terms of field treatments. A 6-inch acre is the amount of soil that would cover an acre of land to a depth of 6 inches.

After 2 months, no significant worm mortality was found. In the second test, worms were similarly exposed to lindane at rates of 32, 64, and 128 lb/A. Smaller, capped containers were used to prevent worm escape at the high dosages. The LD_{50} at 96 hours was computed at 60 lb/6-in A.

Lipa (1958) used a 12% lindane dust in treating a field used to grow potatoes and sugar beets. Plots were treated in May at 1, 2, 3, and 6 lb/A of toxicant; 18 months later the plots treated at 1, 2, and 3 lb/A contained an average of more than twice as many earthworms as untreated plots. However, plots treated at 6 lb/A averaged the same number of worms as untreated plots. Data on worm species and the extent of sampling were not given.

Captan

Captan was tested on Eisenia foetida (sp.?) by Martin and Wiggans (1959). Worms were immersed for 2 hours in solutions containing 0.1, 1, 10, 100, and 1,000 ppm and then kept in peat moss for an additional 24 hours. There was little worm mortality as a result of exposure at 10 ppm or below. All worms died from exposure at 100 or 1,000 ppm. No attempt was made to transfer these data to field application rates of the chemical.

Chlordane

Schread (1952) tested chlordane for control of Pheretima hupeiensis. He used wettable powder as a dust, mixed with water, or mixed with fertilizer. Six months and a year after an application of 43 lb/A, worm activity had ceased. At 64 lb/A, heavy mortality occurred after 2 weeks, and infestations were absent a year later. In another series of tests, 48% water emulsions produced heavy mortality at 20 and 40 lb/A. At 40 lb/A, reinfestations did not occur in the first year. The emulsion acted more quickly than the wettable powder.

Polivka (1953) used technical chlordane at rates of 5, 10, and 20 lb/A on a golf course in Ohio. No reduction in earthworm populations had occurred within 1 month of an April treatment. After 1 year, however, all treated plots had significantly lower earthworm populations than untreated plots. In another test, he used chlordane at 10 lb/A in emulsion form with 1,000, 100, and 9 gallons of water. Earthworm populations were checked each week for 5 weeks after the April treatment, but no significant change was observed, possibly because of the masking effect of the normal population change among earthworms in early summer. Polivka concluded that fall worm populations in one other series of plots treated with chlordane 5 and 6 years previously at 5, 15, and 25 lb/A still were significantly lower than those on control plots. Here again, the extent of the sampling was not presented.

Hopkins and Kirk (1957) estimated the 96-hour LD_{50} of Eisenia foetida, exposed to chlordane, to be 100 lb/6-in A. Exposure was in soil mixed with 5% chlordane dust at rates of 32, 64, 128, and 256 lb/A; observations extended over 4 days.

Doane (1962) found that 10 lb/A of chlordane applied to a sandy soil as either granules or emulsion spray reduced earthworm cast numbers to zero after 18 months. Both Lumbricus terrestris and Allolobophora caliginosa were present before treatment.

DDT

In one of the early reports on the effects of DDT on earthworms, Fleming and Hadley (1945) stated that 100 lb/A of 2.5% DDT dust (presumably 2.5 lb/A actual toxicant) had no apparent effect on Pheretima hupeiensis on golf greens. Greenwood (1945), in a trial incidental to other work, placed 8 earthworms in a pot of soil containing about 100 lb/A of DDT; the worms behaved normally for 14-16 days, then began to show symptoms of toxicity, and all died within a month. Eight other worms in untreated soil remained alive and healthy. Baker (1946) recorded reduced earthworm activity the spring following treatment of an elm grove with a 0.25% DDT emulsion at an unspecified rate per acre.

Richards and Cutkomp (1946) included earthworms (Lumbricus terrestris) in studies they made to determine if there was a correlation between sensitivity to DDT and the possession (or lack) of a chitinous cuticle. The worms showed no ill effects from immersion in colloidal suspensions of DDT in water when the DDT was present at concentrations of 10 ppm and 100 ppm. No attempt was made to convert this resistance to DDT levels encountered in field applications.

Rodale (1948) stated that DDT was instant death to earthworms, but did not provide supporting data.

Goffart (1949) found that earthworms were not affected by soil media containing one part of DDT in 500 (2,000 ppm).

Fleming and Hawley (1950) reported that DDT at 25 lb/A had no effect on earthworms. Earthworm species were not identified. The DDT, in the form of a 10% dust, was applied by mechanical spreaders in a test for control of Japanese beetles.

Polivka (1951) rechecked earthworm populations in plots treated with DDT dust 5 years earlier and found no significant reduction on plots treated with less than 37.5 lb/A. In another series of plots treated at 12.5 and 25 lb/A, he found no effects on earthworms after 42 months (Polivka, 1953). In another series of plots treated with DDT at 25 lb/A, effects on earthworms were not significant after 5 years, but were significant in the 6th year (Polivka, 1953). Sampling errors in these studies may have accounted for the inconsistent results.

Hoy (1955), working in New Zealand, made both laboratory and field tests of the effects of DDT on Lumbricus rubellus and Allolobophora caliginosa. In the laboratory tests, soil of low organic content was mixed with 10% DDT dust (para para' isomer) at rates of 21, 40, and 80 lb/A. At the end of 8 weeks, earthworm populations were significantly lower in the jars treated at 80 lb/A but not in the jars treated at lower rates.

In the field tests, DDT was applied at 2, 30, and 60 lb/A, and population counts were made at the end of 23 and 83 weeks. Worms were not completely eliminated; there were some significant differences, however, but these possibly could have been the result of normal variation of earthworm population distribution.

Hopkins and Kirk (1957) exposed Eisenia foetida to DDT (10% dust) at 15 lb/A for 2 months without any marked worm mortality. Tests were made in Marlboro sandy loam (South Carolina). They reported that tests with DDT up to 256 lb/A gave erratic results.

Barker (1958) sampled soil and earthworms from beneath elm trees that had been sprayed with DDT for Dutch elm disease control. The soil samples contained up to 18 ppm DDT and/or DDE. Whole body analyses of earthworms (Lumbricus terrestris, L. rubellus, Helodrilus spp., and Octolasium lacteum) contained from 53-204 ppm (wet weight). The earthworms appeared not to be affected; however, deaths of robins were believed due to consumption of toxicant-bearing earthworms.

Martin and Wiggans (1959) tested the effects of DDT solutions on Eisenia foetida (sp.?). The worms were submerged for 2 hours in solution of 0.1, 1, 10, 100, and 1000 ppm and then kept an additional 24 hours in peat moss dampened with the solution. Survival counts were then made. There was no earthworm mortality at 10 ppm or lower. Mortality was 20% at the 100 ppm level and 60% at the 1000 ppm level. No attempt was made to correlate these results with field conditions or rates of field application.

Edwards and Dennis (1960) reported no effects on earthworms from soil treatments with 200 lb/A of 5% DDT dust (effective toxicant apparently 10 lb/A). The DDT was mixed to a 6-inch depth on plots 6 feet square and all plots were kept fallow with herbicides (CMPP and Dalapon). Samples were taken at the end of 2 - 3 months. The earthworm species, soil types, and other details were not given.

Doane (1962) tested the effects of DDT on Lumbricus terrestris and Allolobophora caliginosa. He applied DDT at 2.8 and 25 lb/A to plots 20 feet square, using four replications. Granular formulations and water emulsions were used on light sandy soil on May 19 and June 23, 1960. Both worm species were easily collected for toxicant analyses that October. However, in October of the next year, cast counts indicated significantly reduced earthworm populations on those plots treated at 25 lb/A. Populations appeared unaltered on plots treated at 2.8 lb/A. Avoidance reactions by the earthworms were not precluded as a reason for the observations.

Dieldrin

In one phase of his tests, Schread (1952) obtained good worm control with dieldrin applied at 44 lb/A. A 60-square-foot plot of golf-green grass in a nursery was treated with dieldrin "emulsion" in June. The treatment was watered in and soaked again after 24 and 48 hours. Worms were well controlled by August, and there had been no reinfestation a year later. Untreated plots remained heavily infested.

Polivka (1953) treated field plots on an Ohio golf course in two experiments. Plots treated in March with 1, 5, 10, 20, 40, and 80 lb/A of dieldrin contained significantly fewer earthworms in late September than did untreated plots. In the second experiment, plots treated with dieldrin at 1, 5, 10, 15, 20, and 25 lb/A showed no significant differences in earthworm populations after 6 weeks.

Hopkins and Kirk (1957) reported that Eisenia foetida survived treatments of dieldrin at 5 lb/A for 2 months. In a second experiment, the worms were exposed for 4 days to media composed of dieldrin dust mixed with soil at rates of 32, 64, 128, and 256 lb/A of dieldrin. The LD_{50} at 96 hours was computed at 183.2 lb/6-in A.

Luckmann and Decker (1960), studying Illinois fields treated with 2 and 3 lb/A of dieldrin, found no differences in the number of earthworms between treated and untreated plots. Samples of soil 1 foot square and 9 inches deep were taken in both areas, 1 and 4 years after treatment, in both corn and soybean crops. The soil was a sandy loam.

Dieldrin spray at 10 lb/A eliminated cast production by Lumbricus terrestris and Allolobophora caliginosa 18 months after application to a light sandy soil (Doane 1962). Casts were present, but significantly reduced in numbers, where 10 lb/A of dieldrin granules was used.

Endrin

Endrin dust tested in pot experiments at 5 lb/A produced no mortality among Eisenia foetida after 2 months' exposure (Hopkins and Kirk, 1957). In a second experiment, up to 1024 lb/A of endrin gave erratic results.

Patel (1960) used endrin to successfully control earthworms in tobacco seed beds in India. He used a 0.01% emulsion spray at a rate of about 27 lb/A [1 oz 20% emulsifiable concentrate in 12.5 gal water; sprayed at 1 gal/16 sq ft (Imperial gallons)]. Earthworm species and soil types were not identified.

Heptachlor

Polivka (1953) applied heptachlor to plots of 100 sq ft each on an Ohio golf course at rates of 5, 10, and 20 lb/A. Treatments were made in April, and 5 weeks later there were no significant population differences between earthworms on treated and untreated areas. By the following May, however, all treated plots had earthworm population means significantly lower than the untreated areas. The heptachlor probably was applied in dry form. Soil types and earthworm species were not identified.

Hopkins and Kirk (1957) made two series of pot tests of the effects of heptachlor on Eisenia foetida. In the first test, 2 months' exposure to heptachlor at a rate of 7.5 lb/A did not affect the worms. In the second test, worms were exposed for 4 days at rates of 32, 64, 128, and 256 lb/A; the LD_{50} for 96 hours was 163 lb/6-in A.

Smith (1959) studied earthworms on Louisiana fields treated with heptachlor and on untreated fields. Treatments of approximately 2 lb/A of granular heptachlor were applied in late February or early March. Worm population samples were taken at intervals throughout the summer on both treated and untreated land. Final data in this paper showed seasonal fluctuations in earthworm populations that appeared to be unrelated to the heptachlor treatments, although preliminary findings (Glasgow, 1958) had suggested otherwise.

Monuron

Martin and Wiggans (1959) tested the effects of monuron on Eisenia foetida at solution strengths of 0.1, 1, 10, 100, and 1000 ppm. The worms were immersed for 2 hours, then exposed an additional 24 hours in peat moss dampened with the solution. Worm survival was 90% at 1 ppm, 80% at 10 ppm, and nil at 100 ppm and 1000 ppm. No attempt was made to express these results in terms of field applications.

Tetram®[1/]

Tetram was used by Al-Azawi, Norris, and Casida (1961) in experiments designed to find systemic poisons effective against the Dutch elm disease vector, Scolytus multistriatus. The chemical was found to be very stable and also extremely toxic. Beds of Lumbricus terrestris were fed fallen leaves from elm trees that had been implanted with tetram, with the result that 42% of the worms died in 5 days; 60% in 10 days; and 90% in 15 days. Because of the toxicity of tetram to forms other than the one intended, the authors did not recommend its use.

Toxaphene

Hayslip (1948) reported that the use of toxaphene on a golf course in Florida was not effective in controlling earthworms. The chemical was applied in a solution of 1 lb of 25% wettable powder/100 gal water (application rate not given).

Polivka (1953) used toxaphene on golf course plots in April at rates of 10, 20, and 30 lb/A. Earthworm populations had not been affected 1 month later. However, the year following (May), all treated plots sampled had population means significantly lower than the untreated plots. In another series of plots treated with 5, 12.5, and 25 lb/A of toxaphene, earthworm population differences were not significant after 42 months.

Hopkins and Kirk (1957) tested effects of toxaphene on Eisenia foetida in laboratory experiments. After 2 months' exposure at 30 lb/A, 24% of the worms had died, but this was not considered significant. In further experiments, up to 1024 lb/A was used without clear results.

Guthion®[1/]

Hopkins and Kirk (1957) also tested several organic phosphates against Eisenia foetida. They found guthion more toxic than malathion or the chlorinated hydrocarbons. In pot experiments, the worms survived 5 lb/A guthion treatments for 2 months. A 96-hour LD_{50} of 12.2 lb/6-in A was established from results of tests using guthion at rates of 8, 16, and 32 lb/A for a 4-day period.

1/ Reference to trade name does not imply government endorsement of the product.

Malathion

Malathion at 7.5 lb/A did not affect Eisenia foetida in pot experiments lasting 2 months. Using rates of 16, 32, and 64 lb/A, a 96-hour LD_{50} of 37.9 lb/6-in A was established.

Hyche (1956) tested 1% and 2½% emulsion sprays of malathion on earthworm beds in his search for a chemical to control mites. Both of these rates of application (242 and 605 lb/A respectively) significantly reduced the worms. The spray was applied at a rate of 1 gal/12-15 sq ft. He did not report a level that was nontoxic to the earthworms.

Martin and Wiggans (1959) found malathion in solution nontoxic to Eisenia foetida (sp.?) at the 0.1 ppm level but toxic at the 1 ppm level. The worms were immersed in the solutions for 2 hours and then checked 24 hours later after remaining in a peat moss medium dampened with the solution. Mortality of the worms was 60% at 1 ppm and 100% at 10, 100, and 1000 ppm.

Parathion

Goffart (1949) found solutions of parathion more toxic to earthworms than dust-soil mixtures in laboratory tests. Mortality was 10% in 2 days in one part parathion dust per 1000 parts soil (1000 ppm); it was 90% in 3 days in a 0.001% solution (10 ppm), with exposure to immersion lasting only 10 minutes.

Schread (1952) used parathion (plus chlordane) to control Pheretima hupeiensis on golf greens. Between May 13 and June 24, 94.5 lb/A of parathion was applied to a heavily infested golf green. Last counts indicated a 97% mortality by June 28. The treatment included 17 lb/A of chlordane in June. On July 14, the top inch of soil contained 30 ppm parathion. In June, 3 years later, worms still were absent from this green.

Hyche (1956) conducted a series of experiments to find methods for controlling mites in earthworm beds without killing the earthworms. His tests with parathion showed that such differential control was possible with certain concentrations of the chemical. Treatments at 7-9 lb/A (Using 1 pint 25% emulsifiable concentrate or 2 lb 15% wettable powder per 100 gal water) were effective against mites without killing the worms. Higher rates (approximately 242 lb/A in the form of 1% emulsion) killed both earthworms and mites. Tests of a mixture of methyl parathion (24.5%) and parathion (6.2%) in emulsion gave results similar to those for parathion alone.

In his recommendations for control of mites, Scott (1960) included the above treatment of 1 pint 25% emulsifiable concentrate of parathion/100 gal water applied at the rate of 1 gal/12-15 sq ft (7 lb/A). He also recommended the use of 1 lb 15% wettable powder/100 gal water, or just one-half that used by Hyche. This would be equivalent to about 4-5 lb/A.

Satchell (1955) summarized the work of Weber (1953) with the statement that damage to earthworms was found to be greater from parathion "than from B.H.C. or from B.H.C. mixed with D.D.T. The effect of these insecticides was noticeable for 2-3 weeks."

D-D[1]/

Offer (1950) reported that the soil fumigant D-D (dichloropropane-dichloropropene mixture) when applied to the soil at rates of 200-400 lb/A had no deleterious effects upon earthworm populations. No further details were available.

Miscellaneous Chemicals

Lagrange (1946) reported that alizarin, alizarin sulfate, and purpurin were extremely toxic to earthworms.

Khorana and Motiwala (1950) also described several chemicals that were highly toxic to earthworms. The top three in order of toxicity were: 3-phenylumbelliferone, 7-hydroxyflavone, and 6-acetyl-7-hydroxyflavone.

DISCUSSION AND CONCLUSIONS

Resistance of earthworms to all except very heavy doses of chemical was apparent in nearly all studies reviewed. It was apparent also that the formulation of the chemical (dust, emulsion, solution, etc.) influenced the effect on earthworms. In certain studies, the organic content of the soil was important. Several studies suggested that effects may appear slowly, perhaps only after many weeks or months; this is an important possibility that needs firm verification and exploration of causes. Differences in reactions of different species of earthworms seem probable also; few comparative data are available. Meaningful experimental work concerning the effects of pesticides on earthworms appears to be extremely difficult, because of large natural fluctuations in populations and because of the problems of harmonizing laboratory and field results.

1/ Reference to trade name does not imply government endorsement of the product.

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